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What kind of expertise is needed for low energy construction?

Abstract

The construction industry is responsible for 40% of European Union (EU) end-use emissions but addressing this is proving problematic, as evident from the performance gap between design intention and on-site energy performance. There are significant indications of a lack of the expertise needed for low energy construction (LEC) in the UK as this requires ‘energy literacy’ of all construction occupations, high qualification levels, broad occupational profiles, integrated teamworking, and good communication given the complex work processes involved. This research seeks to identify the obstacles to meeting these requirements, the nature of the expertise needed in order to break down occupational divisions and to bridge those interfaces where the main heat losses occur, and the transition pathway implied to achieving this. Obstacles discovered for the UK include a decline in the level, breadth and quality of construction vocational education and training (VET), the lack of a learning infrastructure on sites, and a fragmented employment structure. To overcome these and to develop expertise through enhanced understanding of LEC requires a transformation of the existing structure of VET provision and of construction employment in the UK and a new curriculum based on a broader concept of agency and backed up by rigorous enforcement of standards. This can only be achieved through a radical transition pathway rather than market-based solutions to a low carbon future for the construction sector.

Key words: low energy construction, expertise, transition pathways, labour, vocational education and training

Introduction

The construction industry in Europe is especially affected by the need to confront the increasingly rapid warming of the world because the sector as a whole is responsible for 40% of European Union (EU) end-use CO_2 emissions (Dupressoir 2008). What distinguishes low energy construction (LEC) is the delivery of buildings with extremely low levels of annual energy use (expressed in kWh/m^2 per year) in order to meet national and international carbon dioxide emission reduction goals. With core guidance given in three key EU Directives - the Energy Performance of Buildings (EPBD 2010), the Renewable Energy Sources (RES or RED 2009) and the Energy Efficiency Directive (EED 2012) - the EU Roadmap proposes an 80% CO_2 reduction in building emissions by 2050 to be achieved through energy-efficient building envelopes supported by renewable/low energy building services (EC 2011a). Technically, LEC demands a fundamentally different approach from conventional construction methods, one that recognises the building envelope as a single thermal unit with renewable technologies and as made up of elements that come together through the social interaction of different occupations, including bricklaying, carpentry, plastering, floor laying, insulation, electrical engineering and plumbing. This implies a socio-technical transition framework encompassing both the material and social worlds.

The imperative for LEC raises important questions concerning the expertise required, whether this is available, how it can be developed through vocational education and training (VET) programmes and the knowledge and know-how implied. These questions are addressed in this article and are especially urgent given the current crisis in construction VET in the United Kingdom (UK) as the number of first year trainee entrants in ‘construction craft occupations’ in Further Education (FE) Colleges has reached a historical low of 11,586 in 2015, only a third of whom were undertaking work-based training and only 3,000 an apprenticeship programme (ConstructionSkills 2015). These trainees therefore represent less than 1% of the workforce of about two million and their training continues to be concentrated in the traditional ‘trade’ areas, each covering an ever-narrower scope of activities and largely restricted to National Vocational Qualification (NVQ) Level 2 rather than the Level 3 common in most European countries (Clarkl et al 2013). Whether for retrofitting or new build, LEC requires knowledge of building physics, mathematics, engineering or material behaviour, as well as abstract competences such as reading off drawings, setting out, bridging interfaces and constructing to high precision. This implies a highly qualified workforce and a broad scope of abilities incorporated in different construction occupations. The low level of skills and narrow qualifications of many employed in the industry in Britain and the lack of initial and further training are therefore likely to be detrimental to low energy performance

There is increasing recognition, particularly following the Stern Review of 2006, that a social transition is necessary if energy targets are to be met (ETUC 2004; Steward 2015). As much as 80% of greenhouse gas emissions in the EU originate from firms’ production of goods, suggesting that work sites and processes and chains of production are major polluters (ILO 2011). As building is a major contributor to these emissions, cconsideration of the kind of expertise needed for LEC and the VET most appropriate to developing this relates also to the transition pathway to an energy efficient future. As shown in this article, alternative transition pathways have different implications for knowledge and skill development in construction, (CEDEFOP 2013). For example, one-off short training courses in insulation skills will have vastly different consequences for young people and energy performance compared with comprehensive VET courses for energy literate insulators.

As well as VET, the transition pathway adopted also has implications for employment and working conditions, and for the very organisation of production and the labour process (ETUI 2014; Eurofound 2011; UKERC 2014). Above all, the fragmented nature of construction employment, with high numbers self-employed and employed by agencies and an ever extended subcontracting chain, presents a serious obstacle to achieving effective LEC.

Drawing on comparative European research by the authors on VET, in particular on different construction occupations, this explorative study is about the kind of expertise required to meet energy imperatives in the construction sector and how this can be developed (e.g. Brockmann et al 2010 and 2011; Clarke et al 2013; IG Metall 2014). In developing an appropriate theoretical framework, it draws on the work of Bernstein (2000), Kerschensteiner (Gonon 2009) and Ryle (1949) in relation to the philosophy of education and of Marsden (1999) and Biernacki (1995) in relation to employment and labour. It is largely focussed on the UK and on site-based occupations, though these are not regarded as having a fixed scope of activities, especially given significant differences in different countries. 'Expertise' is referred to the knowledge and know-how required, and thus reliant on the VET system for its development. Thus it is not seen as embodied in the individual or in specific construction occupations, as for instance in the work of Newton (2016) in relation to construction management. The article concludes by considering the kind of curriculum needed to develop LEC expertise and the relativity of this construction expertise to the transition pathway pursued.

Problems with meeting LEC targets

Many countries have embarked on LEC programmes, including developing ultra-low standards such as the Canadian R2000, the Swiss Minergie, the Code for Sustainable Homes Level 6 in the UK, and the German Passivhaus. Three test procedures - air permeability, coheating, and thermal imaging – can be used to assess the pre-occupancy thermal performance of the building envelope (floor, walls/doors, windows and roof). Through these techniques, a reasonable assessment can be made of the building envelope's 'as-built' heat loss and the designed heat loss compared with performance without the additional complication of normalising for occupancy (Johnston and Miles-Shenton, 2009). However, though the imposition of stringent control measures through building regulations should mean that new buildings achieve higher energy efficiency than previously, research has documented a so-called 'gap' between the design and building performance of both low energy new buildings and retrofits (Johnston, et al. 2010). The need to remedy this performance gap is crucial to meeting UK low carbon targets, as laid down in the Climate Change Act of 2008 and by the EU Directives.

As-built performance rests on whether the design elements are possible to construct under site conditions, along with important considerations concerning the competence, know-how and knowledge of building workers or what might be termed their 'energy literacy'. The social relations involved in the construction process are therefore central to understanding the difference between the energy loss envisaged and the actual building performance. They imply a focus on how labour is organised and employed as well as on the quality of the labour involved, including the qualifications of building workers and the VET system in place. This has been recognised by the European Commission (EC) in its *Energy Efficiency Plan 2011* (EC 2011b), which specifically addresses the need for qualified workers, the lack of appropriate training for architects, engineers, auditors, craftsmen, technicians and installers, notably for those involved in refurbishment, and the requirement for ‘new skills’ and ‘environment-conscious’ VET in construction and for adapting ‘curricula to reflect the new qualification needs ’ in order to ‘transition to energy-efficient technologies’ (p.7). To facilitate this transition, the EU has supported an audit of labour availability through the *Build-up Skills* initiative, with National Reports leading to National Roadmaps, which should integrate into the broader EU employment and qualification strategy and are focussed on social rather than purely technical obstacles, especially with regards to upskilling the existing workforce through continuing training.

These national reports have shown that VET for LEC poses particular challenges not only because of its technical demands but also because of the complexity of process management and co-ordination, particularly the cross-occupational co-ordination required. The Build-up Skills overview report notes ‘weaknesses of national education and training systems’ and a ‘shortage of cross-trade knowledge and skills (e.g. installation of few renewable energy systems), including insufficient coordination between occupations and their ‘borderline’ skills and unsatisfactory interdisciplinary training opportunities within upper secondary and continuing education and training systems’ (EC 2014: 64-5). The *Build up Skills* report for

Germany in particular locates the main problem in reducing emissions in: ‘interfaces between trades’ and ‘lack of any understanding for a house/building as one integrated system’ (Build Up Skills 2012: 6-7). The suggestion is that energy requirements can only be met by overcoming obstacles that lie in the VET system (achieving broad and comprehensive know-how) and the building production process (bridging occupational interfaces). Studies across Europe confirm this, indicating a lack of energy literacy and a growing need for transversal abilities within those areas critical to achieving energy efficiency (Zero Carbon Hub 2014).

The imperatives for low energy construction to meet EU 20/20/20 targets introduce new VET requirements that present a major challenge in UK, including: the greater educational input required to achieve energy literacy for all workers concerned; broader qualification profiles to bridge what are in effect social interfaces between the activities of different occupations; learning from feedback; and integrated team working and communication given the complex work processes involved. Sealing and insulating the building envelope is critical to achieving energy efficiency given that air leakages in, for instance, a house typically occur through the physical interfaces between the roof and walls and between the windows and doors and walls. These physical interfaces are at the same time reflected in social divisions between those employed in different occupations, between, for instance the roofer, carpenter, bricklayer, and groundworker, divisions that are not just social but contractual as each comes usually under separate subcontracts. The methods deployed by the builder also need to encompass the supply chain since any change in the quality of components will impact on the final energy efficiency. This suggests a major transformation of the construction process, away from the current fragmented employment system, widespread non-formal on-the-job learning, high labour mobility, and sharp separation between operatives and professionals, towards an integrated system where the different site occupations work together and the divide between operatives and professionals is bridged.

Methodology

This study draws on research carried out by the authors over the past ten years to compare construction qualifications and VET systems in different European countries, as well as more recent work on low energy construction. This research includes: a Nuffield Foundation study to compare the qualifications, skills and competences required for bricklaying, nursing, ICT, and lorry-driving in England, France, Germany and the Netherlands, including the ways these were conceived and their corresponding VET systems (Brockmann et al 2011); a study of bricklaying qualifications in eight European countries supported by the EC to examine the ways in which the mutual recognition of qualifications might be achieved (Brockmann et al 2010); and an EC comparative project of upholstery and cabinet making in six countries to propose core qualification profiles (IG Metall 2014). Each of these research projects involved extensive interviews with FE Colleges, trade unions, and employers. This programme of research has been followed by studies on low energy construction, including visits to sites and interviews with key players in relation to: a Department of Energy and Climate Change (DECC)-supported study of heat pump installations (Gleeson 2015); and a Canadian Social Science and Humanities Research Council project on climate change and work, including in the built environment (Steward 2015). The study here seeks to bring these two programmes of research together, building on the different findings and the many interviews carried out, in order to produce a framework appropriate the development of VET and qualifications for LEC.

The expertise needed for LEC

The distinction made by Ryle (1949) between *knowing how* and *knowing that* is helpful in addressing the nature of expertise needed to meet LEC targets,. For someone *to know that something is* is for them to have command of a body of propositional knowledge, such as some aspects of the principles of construction design, or the particular features of a specific construction site. Know-how refers to the abilities someone has, in this case encompassing knowledge of how to use certain tools, to carry out certain tasks and to carry out higher order activities that involve planning, communication, co-ordination and evaluation. In the German VET system, these abilities are known as ‘*Fähigkeiten*’, as opposed to ‘*Fertigkeiten*’ or ‘skills’ (Hanf 2011), which are probably best translated as ‘transversal abilities’, not ‘transversal skills’ as they are not themselves skills but can be manifested in different skill sets (see also Ryle 1979). For example, successful planning can be carried out in different ways and the mere exercise of ‘planning skills’, such as drawing a flowchart, is not a sufficient condition of planning actually taking place.

One issue therefore concerns knowledge, whilst the other concerns know-how. In terms of knowledge, for example, a key element of LEC is the elimination, as far as possible, of thermal bridges, which allow heat to leave the interior of a building. Thermal bridges can be understood in terms of the physics of heat and energy and workers need to understand: what they are; where they occur; how good design can avoid them; the techniques best employed in avoiding them or reducing their effects.

Whilst the technical details outlining the general theory of insulation continuity and air tightness have been available since the publication of Accredited Construction Details in 2007 (CLG), their importance in terms of heat loss is still generally poorly understood. For low energy construction, thermal bridges may be responsible for circa 30% of building heat losses yet their description and appropriate solutions are not found in mainstream construction training literature. More recently, installer-focused literature such as the Thermal Bridging Guide (ZCH 2016a), aimed at construction occupations such as bricklaying, carpentry and plumbing, has been developed by the Zero Carbon Hub to explain thermal bridging and to provide images of technical solutions for building site use. Only with such knowledge can workers make appropriate on-site judgements about how to implement design solutions in their particular circumstances, liaise with other workers in neighbouring occupations to ensure consistent LEC practice and feedback advice and warnings to appropriate personnel. They also need to have a good grasp of the overall design of the project, where their work fits into it, and how this work interacts with the work of those in other occupations working on the same project.

In terms of know-how, workers need to be able to act in an informed way in full knowledge of the implications of their work for energy conservation, applyingt their knowledge of, for example, thermal bridging, to the way in which they carry out their work. They need to have the task specific competences required to carry out the work, as outlined in, for instance, the Zero Carbon Hub's Builder's Book (ZCH 2015) and Services Guide (ZCH 2016b), which provide some insight into the level of know-how and attention to detail for thermal performance that may be encountered on UK building sites, including through photographic images of poorly installed or entirely missing insulation and unsealed holes in walls and floors. Construction workers also need to be able to communicate and co-ordinate effectively with those in allied occupations to ensure that overlaps are productively managed and that conflicting operations are avoided. In other words, they need to have the personal capability to become autonomous and to champion the reduction in carbon emissions.

Transition pathways to low energy construction

Whilst these are the abilities or expertise required of construction workers for LEC, their development rests on the VET system in place, the way qualifications are framed, and the social transition envisaged in the construction labour process. Paul Hampton (2015), in his incisive attempt to bring labour to the forefront in combatting climate change and to treat the natural or material world (in our case the built environment) and the social world (the quality and organisation of labour) as interdependent, has identified three prevalent frameworks in the wider debates on the dynamic of transition to a low carbon economy. His multi-disciplinary study, combined with Geel's (2011) multi-level perspective on the transition to sustainability, is especially relevant to the problems of achieving LEC by reconciling structural factors relating to the context within which social, political and economic events occur and agency factors referring to action and the political subjects of change. Each of the transition pathways identified by Hampton (2015) implies a different approach to the construction labour process and VET, and hence different kinds of expertise.

The first pathway is market based, seeking to avoid state-led investment and promoting strategies focused on adjusting the market context through instruments such as carbon pricing and consumption taxes, as a viable way of easing the cost of transition or a means of creating jobs (Pearce and Markandya 1989). In terms of low energy construction, this means continuing to rely on the premise that skill shortages will be filled by market demand mechanisms, so that, in accordance with Marsden's (1999) 'production' approach, skills are seen as work-based and training dependent to a large extent on the individual employer and on-the-job learning. Such an approach implies that labour is regarded as a commodity, performing recognized activities in the work process under conditions of limited autonomy linked to a specific output, so echoing what Biernacki (1995) terms 'embodied labour' (Clarke et al 2013). This is much the same conception of labour as Adam Smith (1776/1947) espoused, with the worker trained and paid to fulfil particular tasks, broken down into simple steps and overseen by managers, as similarly envisaged by Frederick Winslow Taylor (1911). In relation to construction, it is also identifiable with Ramioul et al's (2016) 'low-road' approach in their study of energy friendly house construction in Belgium, involving high levels of centralised control and specialisation, a lengthy value chain, erosion of team-based working, and poor job quality.

A second and common transition framework is what has been termed 'ecological modernization', which adds to the first framework policies for employment and social justice, training and retraining, learning and skills development and expresses a broadly positive view of the dominant patterns of technological change and economic development in their potential to deliver sustainability, whilst acknowledging that government policy needs proactive investment and promotion and emphasising the need to invest in green jobs and for a ‘just transition’ towards them (Hajer 1995; Mol et al 2009). This framework accords with Marsden’s (1999) ‘training’ approach, which regards VET as institutionally regulated, related to a person’s ability and certified qualifications, and generally collectively and industrially organised. The labour implied is no longer a commodity but has a mind of its own, though as agent remains restricted by the institutional setting or structure. This second approach is close to Ramioul et al’s (2016) ‘high road’, which is more employee-centred than their ‘low road’, with greater worker participation, empowered teamwork, investments in skills of the workers, and better job quality.

A third framework identified by Hampton (2015) is more radical, suggesting that radical transformation of social and technological arrangements through a coalition of societal actors and stakeholders will be needed to ensure a transition to a low carbon society (Grin et al 2010). According to this ‘radical transition’ approach, to achieve the necessary carbon reductions will require integrated and regulated energy supply, natural resources and transport systems, ‘socially/ environmentally useful production’ and ‘extended producer responsibility’. The approach implies that, through the development of personal capabilities and occupational capacity, labour - or in Biernacki’s (1995) terminology ‘labour power’ - becomes a more active agent with real autonomy to challenge the institutional structures of VET and employment and to champion the reduction in carbon emissions, for instance in the UK through green representatives (Snell and Fairbrother 2010).

This third sociotechnical transitions framework, which involves more knowledge and know-how than is currently required within the sector, therefore raises the wider issue of workers as environmental actors or innovators (Räthzel and Uzzell 2013; Eurofound 2011). The VET system required needs to be broader, akin to that advocated by Georg Kerschensteiner (Gonon 2009), which advocates developing the civic virtues of the worker and consciousness of the impact of occupational activities both on other occupations and on society. The consequence of such a system should be to equip labour with the potential to challenge structures through the knowledge and know how acquired and the expertise to innovate (Winch 2006). It is therefore no longer a system geared only to developing skills but one associated with a broader concept of agency, developing the intellectual and manual capabilities necessary to act autonomously and to plan and manage new and complex processes (Winch 2013). This third orientation indicates the need for interventions in the construction process that are not simply reactive in terms of justice or job protection, but proactively intervene to shape the nature of the green transition. It concurs with Markey et al's (2015) findings that a high degree of substantive – broad and deep – employee participation, with employees and unions providing an important impetus for action, can most effectively reduce carbon emissions.

Problems with developing VET for LEC in UK

In contrast to what is required for LEC, the VET available currently in Britain generally simply pursues the top-down management response associated with the market-based transition pathway and characterised by task based VET and a lack of self-management. This approach has serious consequences for the development of the necessary VET for LEC and for meeting energy targets. It is also a system in crisis, as the number of first year FE trainees in the wood trades has fallen from 13,743 in 2007 to 4,536 by 2015, in bricklaying from circa 9,000 to 2,364, and in plant operation from 4,747 to just 834 (ConstructionSkills 2015). About three-quarters of apprenticeships are in the four main building trades – wood, bricklaying, painting and decorating, and plastering and dry lining, though these constitute little more than half of the forecast requirement for skilled manual trades (CITB 2014). In addition, the vast majority of construction trainees only achieve NVQ Level 2, a qualification too low to then progress to supervisory or managerial levels (Brockmann et al 2010).

Few builders in UK take responsibility for training: indeed, 73% of construction companies have been found to have no training plan and 81% no training budget, with only 19% investing in training (BIS 2013). This is understandable in the light of the high levels of self-employment and the fragmentation of firms and degree of subcontracting in the industry. In 20013/14 nearly half of the total construction workforce of two million came under the special Construction Industry Scheme (CIS) for self-employed workers (UCATT 2015). The structure of employment and labour in the industry need to be radically transformed through a coalition of societal actors and stakeholders if the integrated teamworking as well as the broader occupational profiles required for LEC are to be achieved.

Currently, the key structural characteristic of the construction industry, above all in the UK, is its extreme fragmentation. UK statistics on the number and size of private contractor companies reveal the large number of micro-firms, with 39% of the total 194,000 firms being sole operators and 48% employing between two and seven people. Altogether 94% of companies employ less than 14 people whilst only 0.06% employs over 600 (ONS 2013). In terms of the value of output, whilst the larger companies with over 100 employees dominate all new build projects (with 37% of new housing output) and the repair and maintenance of public housing (44% of output), it is the micro-firms with under five employees that dominate repair and maintenance for private housing (50% of output) and make an important contribution (21%) to the output of private new housing construction. The size of firms potentially involved in LEC is, however, in many ways misleading. A large proportion of sole proprietors are in fact self-employed, whilst many more are falsely classified as self-employed under the CIS scheme, and many small firms are simply acting as subcontractors to the larger firms (Elliott 2012).

Many of those who are classified as self-employed are employed by labour-only subcontractors, usually divided on a trade basis, whether for groundworks, bricklaying, carpentry, painting, plumbing or electrical work. Labour-only subcontracting, self-employment and piecework are especially evident in a number of occupations, from bricklaying through to plumbing. This has dramatic repercussions for LEC, giving rise to sharp contractual divisions between the different areas of work, whether between the walls and the doors or between the walls and the foundations and roof structure. Yet it is precisely at these interfaces that the greatest heat losses occur, as revealed in the various measures of energy performance. The debate concerning the need to form integrated teams of mixed occupations, in order to bridge the occupational divisions that serve to sharpen the interfaces giving rise to heat loss, becomes therefore yet more complex when employment conditions are considered. Not only is much of the workforce self-employed and/or employed through agencies, but the construction process is driven by versions of ‘compulsory competitive tendering’ with sub-contracting and sub-sub-contracting dominant, producing up to ten tiers in the supply chain. These employment conditions impose additional constraints on achieving energy efficient performance, particularly when quality control comes second to achieving completion targets.

The situation is that much more serious given the employer-led nature of the VET system, where trainees depend on employer goodwill to acquire work experience, qualifications and VET (including for green construction), where lobbying by employer trade associations is critical to new qualifications being developed, and where government policy is focussed on work-based apprenticeship and short-fix training courses, appropriate to a market-based transition pathway.

The example of new build traditional masonry well illustrates the extent to which construction qualifications related to initial VET in Britain incorporate or are sensitive to low energy requirements for the dwelling envelope, which refers to solid ground floor slabs, cavity brick walls and timber roofs. Table 1 reveals the extent to which these areas are carried out by those with ‘skilled’ and ‘advanced skill’ qualifications, as well as those operations where there is no formal training available, including ‘groundworks’ (e.g. digging foundations, laying drains and, paving slabs) and concreting. For those areas with formal training, whilst ‘insulation and energy efficiency’ is referred to in NVQ Level 2 and 3 documents for bricklaying, site carpentry and plastering, this is treated as an element in a range of ‘knowledge’ issues and therefore of equal importance to other areas within ‘knowledge of building methods and construction technology'. There is no knowledge requirement to understand the envelope as a single system, no reference to air barriers, air tightness or thermal bridging, no requirement to understand the interplay between the separate envelope workers and final energy performance, and no celebration of the 'thermal literacy' of the construction worker so central to achieving a low carbon future. Where formal VET exists, analysis of the training content for new entrants to the industry identifies a lack of focus on low energy as a key performance objective.

INSERT TABLE 1 HERE

The lack of thermal literacy in VET courses in Britain has resulted in calls, for instance that 'building course curricula be upgraded to require knowledge of basic science involved with climate design' (West 2010: 27). There are two challenges, the first to develop a new workforce attuned to the demands of high-quality LEC and the second to give the existing workforce the ability to engage in high-quality LEC. However, the tendency has been to focus on the latter, resulting in 'specialist', add-on low energy or 'sustainable construction' training schemes being developed to cover air tightness, insulation continuity, etc. in courses that are not an integral part of standard initial VET or even higher education schemes for construction. Indeed the proliferation of certification and awarding bodies and the fragmentation of sets of knowledge, skills and competences to achieve individual or 'specialist' awards complicate any approach to mainstream thermal literacy into standard VET courses. In addition, where previously FE colleges were the key providers of construction VET, there has been a burgeoning of private training providers, often just geared to achieving skill requirements, while educational issues associated with knowledge and know how are downgraded.

This downgrading has been aptly described by Forman and Tweed (2014) with regard to solid wall insulation training. They found that trainers frequently betrayed poor understanding of fundamental concepts and that, whilst there was a heavy emphasis on ‘site proficiency’ (e.g. health and safety, rudimentary process skills, procedural knowledge), there was little emphasis on professionalism and the unintended consequences of improper installation. The quality of site work was also poor, with teams working frenetically in response to ‘pricework’ (pay based on insulated wall area). The need to quality-assure low energy retrofit installations was further exemplified in the UK ‘Green Deal’ programme. Here the requirement for formally certificated workers exposed the difficulties entailed in simply seeking to embed low energy construction by training and certificating particular skills without a comprehensive rethink of the knowledge and knowhow required and the means to provide these through the VET system.

The Green Deal required the development of a Publicly Available Specification (PAS 2030:2012) to identify installer qualification requirements, in order to guarantee the efficacy of the work in meeting the so called ‘Golden Rule’, that the costs involved would be offset by the energy savings. PAS 2030 required that for each installation task at least one member of the workforce, whether employed or subcontracted, should hold a separate qualification in any specific Green Deal role undertaken, as formulated in National Occupational Standards and in particular NVQs. Exemplary qualifications in Building Fabric Measures, such as ‘insulation’, are broken into seven separate qualifications - insulating to cavity walls, external walls, internal walls, hybrid walls, flat roofs, pitched roofs and lofts; in addition, there is a qualification for pipe insulation. A ‘competence ratio’ was to be determined by the installer for each installation in relation to a) the range, scale, geographical spread and complexity of the work being undertaken and b) the supervision and experience of the individual meeting the operative competence requirements for the relevant tasks and the experience of the individuals being supervised. Furthermore, a Green Deal ‘Oversight and registration body’ (GD ORB) was established and guidance written for an ‘Accepted Approach to Installer Surveillance Evaluation’ (GD ORB, 2013).

The Green Deal was launched in January 2013 with a £200 million budget and with Government Ministers projecting 250,000 possible jobs. In July 2015 the government stopped funding the Green Deal Finance Company, effectively ending the programme. Around 10% of Green Deal assessor organisations and 12% of Green Deal installers, an estimated 350 or more companies, had their authorisations removed for non-compliance with the Green Deal Code of Practice (Parliament UK 2015; Gosden, 2015).

There are good reasons for doubting whether such training packages are capable of providing a solution in the medium to long term, unless it becomes possible to rigorously assign liability for imperfect or incomplete execution of elements of projects, with corresponding penalties for construction companies. Should this occur, a very high level of conformity to design specifications would become an imperative for firms engaged in such work, even though proving poor performance remains difficult once the building is occupied due to the wide variation in energy use by different occupants.

The issues surrounding continuing VET in LEC for the existing workforce are complicated by its diverse nature and the uneven degree of preparation and experience. The overwhelming tendency is for industry to follow the market-based transition path and to prepare 'just in time' training packages for different occupations in order to provide a repertoire of skills and procedures intended to facilitate cross-occupational co-ordination. Induction of new site workers and toolbox talks are used on sites where limitation in existing knowledge is recognised and there is a commitment to meeting LEC targets. However, short-term training packages only allow certain abilities to be developed and, within such limitations, practice tends to be protocol-driven, raising workers' awareness of the 'do's and don'ts' of effective LEC within their particular sphere of operations. Indeed, research into heat pump training highlights short courses restricted to only two and three days duration, with an emphasis on 'getting the necessary certificate' to continue earning rather than on 'life-long learning' (Gleeson 2015). To have any effect, such short courses need to be provided for all building workers and this is unlikely to be viable, especially for those who are self-employed, with sub-contractors or agencies.

Instead, schemes such as the nationally recognised quality assurance Microgeneration Certification Scheme (MCS), supported by the Department of Energy and Climate Change and intended to drive up the quality of renewable design and installation, exemplify the approach taken for continuing VET in the workplace. Rather than a long-term solution resting on improved abilities at the level of project execution by those in the occupations concerned, the contractual need for a 'Nominated Technical Person' as the principal duty holder has been introduced.

Short-term, 'quick fix' solutions do not address the issues of understanding process management and co-ordination that are vital to successful LEC and limit the scope for independent and co-ordinated action. They also place a lot of the responsibility on site management, which itself needs extensive preparation. Whilst skilled workers might be assumed to have the knowledge and skill associated with a Level 2 qualification, they need to be prepared to undertake Level 3 work and to have some instruction in the principles of LEC and how these impact on their own occupation. It is for this reason that, for example, Oxfordshire Construction Training Group has developed qualifications at Level 3, leading to a Certificate and Diploma in 'Ecobuilder in Sustainable Construction' supported by apps for smart phones that provide detailed solutions for use on site (CITB 2015).

Curricula, pedagogies, associated practical activity and forms of assessment all need to be developed to provide a viable structure for appropriate qualifications at Level 3, implemented through a cycle of planning, co-ordination (including effective communication), process control and monitoring and evaluation. Preferably programmes should involve intensive site working with relevant occupations as well as simulation, especially in relation to some of the more theoretical components. This suggests far more extensive preparation within the relevant occupations than currently takes place, building on existing knowledge and ability, while at the same time reducing some of the demands on site management for close supervision of work. To meet with any success, elements of construction process knowledge and project life-cycle knowledge need to be incorporated into the continuing training programme. The existing workforce would thus acquire the enhanced understanding of occupational interfaces and the teamwork required to manage these successfully, as well as greater opportunities for independent work. It would not, however, necessarily acquire the broader picture involved in complex construction projects.

To carry though such a programme of retraining represents a significant and extensive challenge for the whole industry. Only if there is greater rigour in the enforcement of standards and if sanctions for non-compliance are at least as great as the costs of implementation is such a training programme likely to be preferred to short-term training packages. However, whilst built on a broader concept of agency, it nevertheless remains confined to the second transition pathway, ecological modernisation, without necessarily challenging the existing VET system or the fragmented structure of the industry in Britain, which remain the most significant obstacle to LEC implementation. It also only refers to continuing VET and not to initial VET for new entrants. Given the crisis in initial construction VET provision in Britain, it is here that opportunities exist for radical transformation of the structure in order to develop the necessary LEC expertise and to address the shortcomings identified in the overall *Build-up Skills* (EC 2014) report, above all the weakness in the VET system and shortage of cross-occupational knowledge, skills and competences.

The examples given in Table 1, coupled with the cancellation of the UK Green Deal and therefore its qualification framework, alongside the declining levels of training, suggest that the third transition pathway, radical transformation of social and technological arrangements, rather than the incremental improvements of the first and second pathways, is appropriate. This implies a transformation of VET away from narrow, low level, task-based training towards a system with a wide occupational scope, encompassing social and civic values as well as a high level of expertise (Winch 2006).

What expertise is needed for LEC in UK?

Traditionally VET in Britain has relied on the development of narrow trade-based skills geared to particular employer needs, and focussed on producing pre-defined outputs (Clarke et al 2013). Increasingly the system has become work-based, with a built-in assumption that learning depends on induction, on the generalisation of a range of practical experiences (Clarke and Winch 2004). However, the knowledge and know-how required for much LEC cannot be directly read from experience or site observations. Nor, given the contractual divisions between the different occupations, is it possible to observe or experience the real problems associated with bridging interfaces between them. Rather than 'manual skills' what are required are abstract competences, implying a model of learning revolving around the application of relevant theories and instances of theoretical propositions to practical situations, and thus depending on deductively relating general principles to particular circumstances. This in turn suggests a higher level of qualification, as proposed in the Richard Review of Apprenticeships in 2012, which recommended far-reaching changes to the way in which VET is conducted in England and a minimum Level 3 qualification. A qualification at Level 3 is necessary for effective LEC because the abilities required range beyond a narrow band of technical skills and encompass heightened technical understanding of the technologies employed, together with process knowledge of the project and the ability to communicate, co-ordinate and evaluate elements of the process with other occupations.

Broader occupational profiles and at the same time integrated teamworking are also required, as each occupation must understand its role in the process and 'buy-in' to the project. Since the joint efforts of several occupations are needed to meet energy standards for the successful completion of the project, an understanding of the work of these different occupations will be necessary. With the envelope air tightness standard, for example, an initial target and a method statement for its achievement are required for all types of buildings, and then each occupation has to realise its role in creating an envelope that meets the design specification. For the masonry build, bricklayers, plasterers, window fitters and plumbers are all involved. Another example of where cross-occupational knowledge is needed is insulation completeness plus the 'thermal bridges' that occur at all junctions and openings; bricklayers, floor layers, carpenters and roofers need to co-ordinate their work to meet the target 'fabric energy efficiency'.

To ensure thermal comfort and public health, the building then requires space heating and/or cooling, domestic hot water and lighting. Provided the fabric energy efficiency has been met, reducing heating and cooling needs to the absolute minimum, the selection of heating and cooling appliances demands attention to their product efficiency, their fuel or power source and emissions. New low and zero carbon technologies that replace boilers with heat pumps, micro-combined heat and power, and solar thermal (solar hot water) provide the opportunity to offset emissions through the generation of renewable power (electricity) and/or renewable heat. However, unlike boilers, heat pump performance is particularly sensitive to poor design, installation and operation and successful installation requires understanding quality engineering design and the problems associated with the handover to the user (e.g. commissioning, controls setting and the ability to explain these) (Gleeson, 2015). For most buildings, integrated renewable generation will entail photovoltaics and/or solar thermal installations where renewable output is deemed as ‘off-setting’ and provides net zero or nearly zero emission buildings.

All built environment occupations need enhanced VET and increased occupational scope for LEC to succeed, so that workers can carry out a wider range of operations relevant to LEC than is currently the case with, for instance, the narrowly trained English bricklayer (Brockmann et al 2013). LEC workers need to understand and evaluate the principles of LEC, including the technologies employed and how these work within a low energy building, as well as the conditions for the successful execution of a LEC project and the principal factors that can cause it to go wrong. Their curriculum needs to embrace the principles concerning why certain activities are carried out in the way and the sequence in which they are, as well as how such principles are realised in practice, appreciation of which can be taught in relation to some observational work on site.

The broad occupational profiles thus envisaged require a more detailed specification and differentiation of abilities and knowledge than are currently required in construction VET documentation. There needs to be detailed emphasis on the systematic knowledge required of workers, especially in, for example, the physics of heat transfer than is currently the case. Crucially the development of the necessary transversal abilities needs to be tightly specified together with the contexts in which they will be exercised, for example in communication and co-ordination with related occupations.

How to build the expertise needed

What would such a curriculum look like? In order to answer this, we propose the adoption of a Bernsteinian framework for the organisation of knowledge (Bernstein 2000), supplemented by the Transparency Tool developed in connection with the SQF-Con Project (Syben 2009) and the Bricklayer Project (Brockmann et al 2010). Bernstein classifies different kinds of curricular knowledge as follows: *singulars* are established subjects which are pursued without immediate practical aims in mind; *regions* are singulars which are combined and reconfigured for practical and professional purposes; and *fields of practice* are areas of specialised professional practice (Young and Muller, pp.13-14). Thus physics is an example of a *singular*, construction engineering *a region* and the construction sector a *field of practice*.

A curriculum for construction professionals working in LEC needs to draw on all three forms of knowledge. Thus, a selection from physics, for example concerning conductivity, is desirable for the understanding of how thermal bridges work. Practitioners would need to apply knowledge of construction engineering connected with LEC technologies, such as insulation and heat pumps in their field of practice. Although simulation should play a role, ultimately operation within the field of practice is necessary for secure development of these abilities and for the *tacit knowledge*, the fine-grained practical ability of the professional, necessary to successful practice and or the development of LEC abilities (Gascoigne and

Thornton 2013, Polanyi 1958; Hutchinson and Read 2011). Practitioners should also have a good understanding of the overall LEC construction process, along the lines of the German '*Stufenausbildung*', whereby a general introduction to construction is given in the first year of construction VET, followed by specialisation into areas such as civil engineering in the second, and only in the final year a focus on a particular construction occupation such as bricklaying (Streeck and Hilbert 1991). The curriculum choices to be made in this radically transformative approach to LEC are summarised in Table 2.

INSERT TABLE 2 HERE

Conclusions

Ultimately the concern for all should be that carbon dioxide reduction targets will be missed due to inadequacies in the VET and qualification systems and the organisation of the production process. For these obstacles to be overcome, it is essential not only to appreciate the role and value of labour, as agent or subject of production, but also to involve the workforce in transforming the VET system and the labour process for a low carbon future. As we have found, for LEC to succeed it is vitally important for each occupation to know what the other is doing, but the integrated teamwork needed to prevent energy loss requires a less extensive subcontracting chain and more direct employment if the different occupations are to work more closely together and a learning infrastructure is to exist. An extensive initial and continuing VET programme is needed to enhance knowledge and know-how, based on broad occupational profiles and careful attention to the application of theoretical propositions. These requirements for LEC expertise imply a radical transformation of both the structure of the industry and the VET system, to be achieved by enhancing the role of labour as an agent of production. They also suggest that the nature of the expertise actually developed is relative to the transition pathway adopted.

References

Bernstein B. (2000) *Pedagogy, Symbolic Control and Identity: Theory, Research, Critique*, New Jersey, Rown and Littlefield

Biernacki, R. (1995) *The Fabrication of Labour: Germany and Britain 1640-1914.* California Press, Berkeley.

BIS (2013) *UK Construction, an economic analysis for the sector,* Department for Business, Innovation and Skills, London

PAS 2030 (2012) *Improving the energy efficiency of existing buildings. Specification for installation process, process management and service provision,* Edition 2, British Standards Institute, London

Brockmann, M. Clarke L. and Winch C. (2010) *Bricklaying is more than Flemish bond: bricklaying qualifications in Europe),* European Institute of Construction Labour Research (CLR), Brussels

Brockmann, M., Clarke, L., Hanf, G., Méhaut, P., Westerhuis, A., Winch, C. (2011) *Knowledge, Skills, Competence in the European Labour Market: What's in a Vocational Qualification?,* Routledge, Oxford

Build up Skills (2012) *Vocational education and training for building sector workers in the fields of energy efficiency and renewable3 energy,* German report by Peter Weiss, Richard Rehbold and Elisa Majewski, Intelligent Energy Europe, September

CEDEFOP (2013), *Skills for Green Jobs: European Synthesis Report,* European Centre for the Development of Vocational Training, Thessaloniki

Clarke, Linda and Christopher Winch (2004) Apprenticeship and Applied Theoretical Knowledge, in *Educational Philosophy and* Theory, 36/5, November, 509-521

Clarke L., Winch C. and Brockmann M. (2013) Trade-based skills versus Occupational Capacity: the example of bricklaying in Europe, *Work, Employment and Society,* Dec., 27(6), 932-951

CITB (2014) *Skills and Training in the Construction Industry,* June, Bircham Newton: Construction Industry Training Board, Bircham Newton

CITB (2015) 'Designed by buildings, for builders', *Training Group News Magazine,* May, Construction Industry Training Board, Bircham Newton

CLG: Department of Communities and Local Government (CLG) (2007) *Accredited construction details*, Communities and Local Government, London

ConstructionSkills (2015) *Training and the Built Environment 2014,* CITB, Bircham Newton.

Dupressoir S. (2008) *Climate Change and Employment: Impact on employment in the European Unon-25 of climate change and CO2 emission reduction measures by 2030,* European Trade Union Institute, Brussels

Elliott J. (2012) *The Great Payroll Scandal,* London: Union of Construction, Allied Trades and Technicians (UCATT), London

ETUC (2004) *Climate change – avenues for trade union action*, European Trade Union Confederation, Brussels

ETUI (2014), *Climate Change: implications for employment,* European Trade Union Institute, Brussels

Eurofound (2011) *Industrial Relations and sustainability: the role of social partners in the transition to a green economy,* European Foundation for the Improvement of Living and Working Conditions, Dublin

European Commission (EC) (2011a) *A Roadmap for moving to a competitive low carbon economy in 2050*, European Commission, Brussels

European Commission (EC) (2011b) *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and The Committee of the Regions: Energy Efficiency Plan 2011*, European Commission, Brussels

European Commission (EC) (2014) *Build-up Skills: EU Overview Report, Staff Working Document,* Intelligent Energy Europe, European Commission, Brussels

Forman, T and Tweed, C (2014) Solid wall insulation retrofit in UK dwellings: Critical factors affecting management and quality *In:* Raiden, A B and Aboagye-Nimo, E (Eds) *Proceedings*

30th Annual ARCOM Conference, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 1367-1376.

Gascoigne, N. and Thornton, T. (2013) *Tacit Knowledge*, Acumen, Durham

Geels F.W. (2011) 'The multi-level perspective on sustainable transitions: responses to seven criticisms', in *Environmental Innovation and Societal Transitions,* 1, pp 24-40

Gleeson C. P. (2015) Residential heat pump installations: the role of vocational education and training, in *Building Research and Information,* 11 September, Vol. 44/4, pp 394-406

Gonon P. (2009) *The Quest for Modern Vocational Education – Georg Kerschensteiner between Dewey, Weber and Simmel,* Peter Lang, Oxford

Gosden E. (2015) 'One in ten Green Deal companies 'struck off' for breaking the rules', *The Daily Telegraph* 14 March 2015.

Green Deal ORB (2013) *GDCAP 01 Accepted Approach to Installer Surveillance Evaluation*. Green Deal Oversight and Registration Body, Version 2, Online http://gdorb.decc.gov.uk/installers/installer-guidance Accessed 27 July 2016

Grin J., Jan Rotmans, Johan Schot (eds) (2010) *Transitions to Sustainable Development, New Directions in the Study of Long Term Transformative Change*, Routledge, London and New York

Hajer M. (1995) *The Politics of Environmental Discourse: Ecological Modernization and the Policy Process,* Oxford University Press, Oxford

Hampton P. (2015) *Workers and Trade Unions for Climate Solidarity: tackling climate change in a neoliberal world,* Routledge, London and New York

Hanf, G. (2011) The Changing Relevance of the Beruf in Brockmann, M., Clarke, L., Winch, C. (2011) *Knowledge, Skills and Competence in the European Labour Market*, Routledge, Abingdon, pp. 50-67

Hutchinson, P., Read, R. (2011) De-mystifying tacit knowing and clues: a comment on Henry et al. *Journal of Evaluation in Clinical Practice*, 17, 5, pp. 944-947

IG Metall Vorstand (2014) *Transparency for Upholstery and Cabinet Making Qualifications and Quality in the European Furniture Industry: Bolster Up,* September, Frankfurt on Main

International Labour Organization (ILO) (2011) *Towards a Greener Economy: the social dimensions,* International Institute for Labour Studies IISL, 116 p.

Johnston, D. and Miles-Shenton, D. (2009) Airtightness of UK dwellings. *In:* Dainty, A.R.J. (Ed) *Procs 25th Annual ARCOM Conference,* 7-9 September 2009, Nottingham, UK, Association of Researchers in Construction Management, 271-80.

Johnston, D, Wingfield, J, Miles-Shenton, D. (2010) *Measuring the fabric performance of UK dwellings,* Proceedings of the Association of Researchers in Construction Management (ARCOM) Twenty-Sixth Annual Conference, 6-8 September

Markey R., McIvor J. and Wright C.F. (2015) Employee participation and carbon emissions reduction in Australian workplaces, *The International Journal of Human Resource Management,* June, Vol. 27/2, pp 173-191.

Marsden, D. (1999) *Theory of Employment Systems: microfoundations of societal diversity*. Oxford University Press, Oxford.

Mol, A.P.J., Sonnenfeld, D.A., and Spaargaren, G., (eds.) (2009) *The Ecological Modernisation Reader: Environmental Reform in Theory and Practice*, Routledge, London and New York

Newton S. (2016) 'The being of construction management expertise', in *Construction Management and Economics,* April, pp. 1-13

ONS (2013) *Housing and Construction Statistics,* Office of National Statistics, London

Parliament UK (2015) *UK Parliament Green Deal Scheme: Written question – 224408,* 12 February

Pearce DW and Anil Markandya (1989) *Blueprint for a Green Economy*, Earthscan

Polanyi, M. (1958) *Personal Knowledge,* Routledge, London

Ramioul M. Benders J. van Peteghem J. (2016) 'Green construction and team design: low road and high road teams to build energy-friendly houses', *World Review of Entrepreneurship, Management and Sustainable Development,* Vol 12, No. 1, pp 33-49

Räthzel, Nora und David L. Uzzell (2013) *Trade unions in the Green Economy,* Routledge, London and New York

Richard D. (2012) *The Richard Review of Apprenticeship,* November, School for Startups, London

Ryle, G. (1949) *The Concept of Mind*, Hutchinson, London.

(1979) *On Thinking*, Hutchinson, London.

Smith, A. (1776/1947) *Wealth of Nations.* Volume 1. Everyman's Library, London

Snell, D & P. Fairbrother (2010) Unions as Environmental actors, *Transfer* 16(3) 411-424

Stern, Nicolas. (2006) *Stern Review Report on the Economics of Climate Change*. HM Treasury, Cabinet Office, London

Steward F. (2015) *Policies and practices to promote work enhancing pathways in the transition to a low carbon economy,* ACW International Policy Working Group Report, Policy Studies Institute, London

Streeck, W. and Hilbert J. (1991) Organised Interests and Vocational Training in the West German Construction Industry, in Rainbird H. and Syben G. (eds) *Restructuring a Traditional Industry,* Berg, New York

Syben G. (2009) *Sectoral Qualifications Framework for the Construction Industry in Europe,* BAQ Forschungsinstitut, Bremen

Taylor F.W. (1911) *The Principles of Scientific Management,* reprinted by Lightning Source UK Ltd.

UCATT (2015) *Sharp growth in false self-employment in construction,* Press statement 13 January, Union of Construction, Allied Trades and Technicians

UKERC (2014) *Low carbon jobs: The evidence for net job creation from policy support for energy efficiency and renewable energy*, by Blythe, W, Gross, R, Speirs, S, Nicholls, J, Dorgan, A and Hughes, N, UK Energy Research Centre, London

West S. (2010) *Airtight and super-insulated construction techniques,* International ISS Institute, Australian Government

Winch C. (2006) 'Georg Kerschensteiner – founding the dual system in Germany', *Oxford Review of Education,* Vol. 32, No 3, July, pp. 381-396

Winch C. (2013) Education and Broad Concepts of Agency, *Educational Philosophy and Theory*, 45 (12), 1205-1218

Young M. and Muller J (2014) From the sociology of professions to the sociology of professional knowledge, in Young and Muller (eds), *Knowledge, Expertise and the Professions*, Routledge, Abingdon

ZCH (2014) *Closing the gap between design and as-built performance.* Evidence Review Report, Zero Carbon Hub, London

ZCH (2015) *Builder's book: An illustrated guide to building energy efficient homes*. Zero Carbon Hub, London

ZCH (2016a) *Thermal bridging guide: An introductory guide to thermal bridging in homes.* Zero Carbon Hub, London

ZCH (2016b) *Services guide: An illustrated guide to building services in new homes*. Zero Carbon Hub, London

Table 1: Thermal skills required for different building elements

Envelope Element	**Nature of VET and qualifications**	**Thermal Skills required**
Ground floor slab	No formal VET. Site experience by general labourer	Horizontal insulation of the slab with vertical insulation to prevent thermal bridging at perimeter
Walls	Bricklaying NVQ levels 2 and 3	Cavity wall insulation. Insulation must be butted together and be complete at corners and breaks in the wall fitted with insulated cavity closers. Air circulation behind or through insulation significantly reduces its impact. Bricklayers need to understand the role of thermal bridging. There is no mention of air tightness or thermal bridges in NVQ levels 2 and 3.
Openings (windows & doors)	No formal VET. These are fitted by many occupations including bricklayers, carpenters, general builders, specialist window fitters.	Window fitting is traditionally the role of the carpenter but with newer materials, such as PVC, aluminium and specialist glazing those carrying out the fitting vary from the general building labourer to the window supplier. This is central to air tightness programme since windows fill a hole in the wall. An NVQ Diploma in Fenestration was developed for the UK Green Deal programme.
Loft insulation	No formal VET.	No formal VET in insulation. Six separate NVQs at Level 2 were developed for the UK Green Deal in 'Insulation & Building Treatments'.
Plastering	Generally Plastering NVQ level 2	The wet plaster seals the envelope to act as the 'air barrier'. No mention of air tightness in the NVQ level 2.
Builders openings	Various/bricklayer/labourer. Often no formal VET.	Holes in envelope for services (water, drainage, cables, etc.) break into the 'air barrier'

Source: CITB Qualification Details. For example: Level 2 Diploma in Bricklaying DIP 102/2, Level 2 Diploma in Plastering, etc. Revised March 2009.

Table 2: Outline of a Transparency Framework for LEC professional Qualifications

<table>
<tr><th colspan="7">Aims of qualification</th></tr>
<tr><th colspan="2">vocational</th><th>civic</th><th colspan="4">liberal</th></tr>
<tr><td colspan="2">Yes</td><td>Yes – includes critical appreciation of the construction industry and barriers to LEC</td><td colspan="4">Yes, allows scope for continuing personal development</td></tr>
<tr><th colspan="7">Attributes</th></tr>
<tr><th colspan="2">knowledge</th><th>know-how
Each characteristic presupposes possession of the one above (Apart from skill)</th><th colspan="4">personal characteristics</th></tr>
<tr><td colspan="2"></td><td>Mastery of technique</td><td colspan="4"></td></tr>
<tr><td>systematic</td><td>non-systematic</td><td>Skill
Specific abilities connected with installation and evaluation of LEC technologies, including development of appropriate tacit knowledge</td><td colspan="2">individual
Curiosity
Independence
Self evaluation</td><td colspan="2">social
Co-operation, ability to see different points of view</td></tr>
<tr><td>Technical theory, including some physics and engineering</td><td>Contingent facts (e.g. local conditions)</td><td>Transversal abilities
Co-ordination
Communication
Evaluation
Negotiation</td><td>Work-place
Yes</td><td>Other Locations
Yes, including simulations and classroom</td><td>Work-place
Yes</td><td>Other Locations
Yes, including simulations and classroom</td></tr>
<tr><td>Normative theory
Legislation governing LEC and barriers to making it effective</td><td>Local procedures</td><td>Process management ability
Understanding of LEC process</td><td colspan="4"></td></tr>
<tr><td>Social science theory
Understanding the role of LEC in contemporary debates and constraints on its introduction.</td><td>Materials
insulation</td><td>Occupational capacity
Understanding of overlaps with other occupations</td><td colspan="4"></td></tr>
</table>

Source: Elaboration of Transparency Tool (Brockmann et al 2010) applied to LEC